Evaluation of the isospin asymmetry of the nucleon structure functions with CLAS++

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The possibility to estimate the isospin symmetry breaking effects in the non-perturbative part of F_2 structure function of the charged lN deep-inelastic scattering data, which will provide CLAS++ detector of the upgraded TJNAF machine at $Q^2 \approx 2$ GeV^2, is discussed. The problems of the Gottfried sum rule extraction are also considered.

1. INTRODUCTION

First experimental evidence of the isospin asymmetry in structure functions (SFs) $F_2^{lp}(x,Q^2)$ and $F_2^{ln}(x,Q^2)$ came from earlier studies of deep-inelastic scattering (DIS) at SLAC. The Gottfried integral was extracted from the NMC measurement at CERN [1]

$$I_{\rm GSR}(Q^2 = 4~{\rm GeV}^2) = \int_0^1 \frac{dx}{x}\left[F_2^{lp} - F_2^{ln}\right] = 0.235 \pm 0.026 \qquad . \tag{1}$$

This result is significantly different from the prediction of the quark-parton model, 1/3. It is not possible to describe this difference neither by the order $O(\alpha_s^2)$ perturbative QCD corrections, nor by a twist-4 non-perturbative $1/Q^2$ contribution [3]. These experimental results caused the discussion of the isospin symmetry breaking effects (see, e.g., [4, 5]). It was realized, that in order to understand (1) one needs to assume a light-quark asymmetry of the nucleon see, $\overline{u}(x) < \overline{d}(x)$, which has a non-perturbative origin. This concept found an additional experimental support in the analysis of Drell-Yan process and the semi-inclusive DIS [5].

However, it must be commented that the interpretation of the NMC result (1) can be affected by both the uncertainties because of nuclear corrections (since the deuterium was used as effective neutron target) and low-x extrapolation. These problems were not adequately addressed in Ref.[1].

*Supported by RFBI Grant N 03-02-17177

†Supported by RFBI Grants N 03-02-17047, 03-02-17177

A more sophisticated extraction of the isospin asymmetry from DIS requires both the improvements in the accuracy of the measurements and the extension of the kinematic region of data. In this respect we note that the planned experiments after TJNAF upgrade to 12 GeV beam energy will significantly improve the accuracy of the measurement of F_2 in the region of intermediate Q^2. The kinematic region accessible with one of its detectors, CLAS++, is shown in Fig. 1. It can be seen that $x = 0.1$ is the lowest possible value of x for DIS events ($Q^2 > 2$ GeV^2).

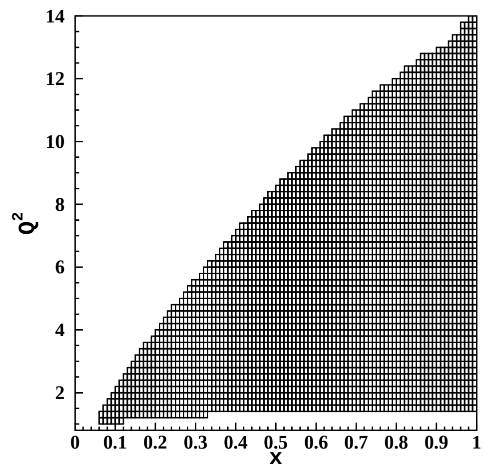

Figure 1. The shaded area shows the kinematics accessible in the inclusive electron scattering experiment with CLAS++ in the (Q^2, x) plane.

Unfortunately the region $x < 0.1$, which is crucial for the evaluation of the Gottfried sum rule, can not be directly probed at this machine. For this reason in what follows we discuss two possibilities to study the isospin asymmetries using data from upgraded TJNAF machine.

2. ISOSPIN ASYMMETRY IN STRUCTURE FUNCTIONS

One possible way to study the isospin asymmetries is to perform a combined analysis of (future) TJNAF data and NMC data at low x, or to extrapolate future TJNAF data to the region of low x using different sets of parton distributions, e.g. the one of Ref.[6]. Figure 2 shows the difference $F_2^p - F_2^n$, extracted from the Next-to-Next-to-Leading order QCD analysis of the world experimental data on the charged lepton-nucleon DIS cross-section [7]. Two solid lines give a band of the isospin asymmetry for the leading twist term and the dashed lines give the band accounting for the twist-4 term. The latter one turned out to be small, like in the first moment Gottfried sum rule [3] and for higher moments as well [7]. However, the dominant uncertainty in the isospin asymmetry is given by non-perturbative effects. New CLAS++ data will give a better constraint on the twist-4 term in the isospin symmetry breaking effects in DIS in the non-resonance region, which for $Q^2 = 2$ GeV^2 corresponds to $x \leq 0.5$. This will allow a more sophisticated treatment of higher-twist terms in the analysis of F_2 data, similar to those in Refs. [8, 7].

The experimental methods of TJNAF measurement of the neutron structure F_2 from the deuteron target allows to eliminate a certain type of nuclear corrections by using the proton recoil detector. Such a recoil detector for CLAS is now under construction at

Jefferson Lab [9]. New hardware will not affect the accessible in CLAS kinematics, which due to almost 4π acceptance permits to measure the inclusive cross section simultaneously in a wide region of x and Q^2 [8]. Therefore, after TJNAF upgrade to 12 GeV beam energy, a combination of two measurements – the measurement of the neutron F_2 from the deuteron target using the proton recoil detector and the measurement of the proton F_2 from the hydrogen target – will allow the extraction of isospin symmetry breaking effects. The measurement of the neutron structure function is already planed at CLAS, while the extraction of the proton structure function F_2 does not require an additional beam time and can be performed within an analysis of electron run data collected during other experiments, as it was done in [8].

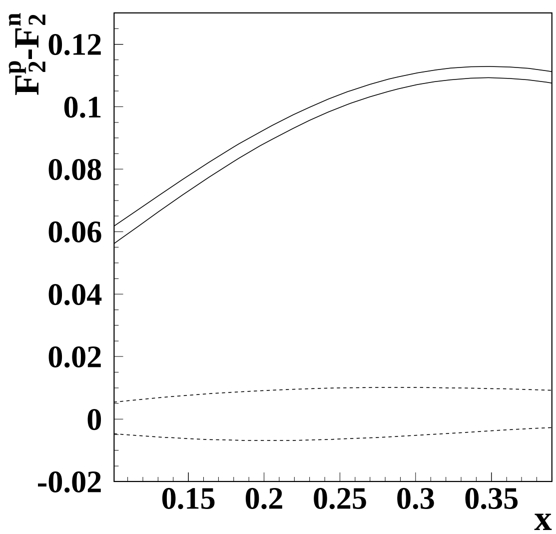

Figure 2. The bands for the leading-twist (solid) and the high-twist (dashes) contributions to the isospin asymmetry of the structure function F_2 at $Q^2 = 2$ GeV^2

3. THE GOTTFRIED SUM RULE

The share of the Gottfried sum rule which is covered by CLAS++ data, according to kinematics shown at Fig. 1, is presented in Fig. 3. This estimate is based on parameterizations of F_2^{ep} and F_2^{eD} from Refs. [10, 11]. In the interval of Q^2 from 2 to 3.5 GeV^2 CLAS++ data can provide more than a half of the value of the Gottfried integral, assuming the x dependence of the proton and neutron structure functions is given by the parameterizations of Ref. [10, 11]. These parameterizations are quite reliable and give the value of Gottfried integral 0.2314 at $Q^2 = 4$ GeV^2 which is very close to the value 0.235±0.026, obtained at this Q^2 by NMC collaboration [1].

However, it is obvious, that even at $Q^2 = 2$ GeV^2 the major uncertainties of the measurement of the Gottfried sum rule at CLAS++ come from the extrapolation to the region $x < 0.1$. Moreover, even the uncertainties of the well-known NMC result (1) may be underestimated because of nuclear effects. In order to illustrate the integral strength of nuclear effects we have calculated the ratio

$$R_{\rm GSR} \;=\; \frac{\int_{x_{\min}}^{x_{\max}} dx \left(2F_2^p(x,Q^2) - F_2^D(x,Q^2)\right)/x}{\int_{x_{\min}}^{x_{\max}} dx \left(F_2^p(x,Q^2) - F_2^n(x,Q^2)\right)/x} \,. \tag{2}$$

In Eq.(2) F_2^D is the deuteron structure function and the integration is taken over the interval of Bjorken x which is linked to experimental conditions. In the absence of nuclear corrections $F_2^D = F_2^p + F_2^n$ that gives $R_{\rm GSR} = 1$. The effect of nuclear corrections on the ratio $R_{\rm GSR}$ as a function of the cut $x_{\rm min}$ is shown at Fig. 4. In this calculation we used the model of the deuteron structure function of Ref.[12], the proton and the neutron structure functions were calculated using the PDFs of Ref. [6] and the upper limit of integration in (2) was fixed to $x_{\rm max} = 0.4$. We observe about 3% (negative) nuclear correction at $x_{\rm min} = 0.1$ and at fixed $Q^2 = 2\,{\rm GeV}^2$. However, the nuclear correction becomes positive and its magnitude rises as $x_{\rm min}$ decreases. We remark that the rise of the magnitude of nuclear correction in this region is because $F_2^D < 2F_2^p$ at small x (this inequality was verified by the E665 data [13]) and because of the factor $1/x$ in the integrands in Eq.(2).

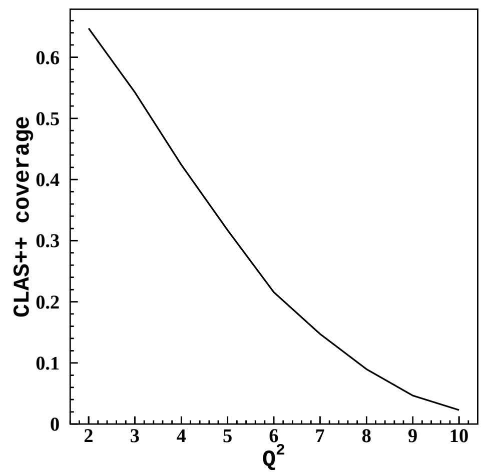

Figure 3. The share of the Gottfried sum rule accessible at CLAS++ data calculated using the parameterizations of F_2^p and F_2^d [10, 11] and the kinematics of Fig. 1.

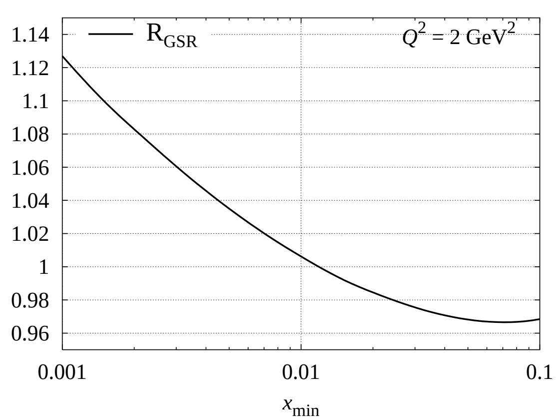

Figure 4. Ratio (2) as a function of the cut $x_{\rm min}$ computed at $Q^2 = 2\,{\rm GeV}^2$.

The Gottfried integral can be extracted from hydrogen and deuterium data as

$$I_{\rm GSR}^{exp} = \int \frac{dx}{x}\left(2F_2^p(x,Q^2) - \frac{F_2^D(x,Q^2)}{R_2(x,Q^2;D/N)}\right) \quad , \tag{3}$$

where the function $R_2(D/N) = F_2^D/(F_2^p + F_2^n)$ provides a correction for nuclear effects. An accurate model of this function has recently become available from the analysis of Ref.[12].

Note, however, even if the effects of nuclear corrections will be fixed the uncertainty of extrapolation to low x using different modern sets of parton distributions of Refs. [6], [15], [14] persists.

To conclude, the extraction of the Gottfried sum rule is difficult, but rather interesting problem. Its studies will help to illuminate the effect of light-quark flavour asymmetry $\overline{u}(x) - \overline{d}(x)$ as well as to test different extractions of $\overline{u}(x)$ and $\overline{d}(x)$ at low x and clarify the reasons for these differences.

4. ACKNOWLEDGEMENTS

This contribution is the main updated part of the talk of one of us (ALK) at Baryons 2004 Conference, Palaiseau. ALK is grateful to the members of Local Organizing Committee and in particular to M. Cuidal for hospitality in France. The research of SIA was also supported in part by the Russian Ministry of Science grant NSh 1695.2003.2.

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